REACTIONS OF AIR TRANSPORT FLIGHT CREWS TO DISPLAYS OF WEATHER DURING SIMULATED FLIGHT

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Flightdeck Display Research - Introduction

- PI Flightdeck Display Research from 1992 to Present
  - Auditory
  - Visual
  - Mistrust of Signals
- Participation in NFFP program, Summer 2002
- Discussions with Jon Jonsson, Paul Stough
- Grant authoring, submission in Fall 2002
- Subsequent funding in Fall 2003

Flightdeck Display Research - Introduction

- Grant Plan, Approach
  - Discussion with NASA, and the FAA/NASA Weather Workshop, Identified Several Key Variables of Interest:
    - Weather Information Reliability
    - Flight Crew Team Activities
    - Combined Weather Info Presentation in the Cockpit
    - VFR/IFR Incursion
    - Display Formatting
    - Workload and Situation Awareness

Flightdeck Display Research - Introduction

- The general goal of cockpit display design: ensure that displays present timely, useful information.
- An important aspect: fostering adequate situation awareness.
- Pilots must make challenging flight decisions when flight conditions deviate from trained scenarios.

Flightdeck Display Research - Introduction

- Wickens (2003) proposes seven principles to drive display design:
  - Information Need
  - Legibility
  - Proximity Compatibility
  - Pictorial Realism
  - Principle of the Moving Part
  - Predictive Aiding
  - Discriminability

Flightdeck Display Research - Introduction

- Some of the most pronounced challenges surround the display of weather in the cockpit.
  - Large number of data sources (TAFs, METARs, FAs, AIRMETs, NOTAMs, PIREPs, SIGMETs, Onboard and NEXRAD)
  - Variability in reliability
  - Advantages of integrated NEXRAD
  - Advantages of onboard weather

Flightdeck Display Research - Introduction

- According to Sly & Hartmann, weather induced route deviation decisions are influenced by
  - Type of Hazard
  - Distance or Time in Weather
  - Probability of Hazard Occurrence
  - Coverage or Density of Hazard
  - Personal Preferences
  - Fleet Wide Optimization
  - Mission Constraints
  - Carrier Philosophy
  - Aircraft Type
  - Severity of Weather

Flightdeck Display Research - Introduction

- Onboard vs. NEXRAD – Implications for flight crew trust
  - Individuals may overtrust or undertrust automated systems, and exhibit degraded performance (Parasuraman & Riley, 1997).
  - Operators may mistrust alarm systems that demonstrate frequent false alarms (Bliss, 1993).
  - These problems may be compounded for weather sources that conflict.

Flightdeck Display Research - Introduction

- Further implications may exist because of teamed reactions (Bliss & Fallon, 2003).
  - Foushee (1982) and others have pointed out importance of cockpit resource management.
  - Though work has been done to study flight crew communication and coordination, this is lacking for information sources of questionable or conflicting reliability.
  - Risk of weather events may interact with perceptions of display reliability (Latorella & Chamberlain, 2002).

Flightdeck Display Research - Introduction

- July 10-11, 2002: FAA/NASA Human Factors Weather Research Coordination Effort at NASA Langley. Emphasis on Needed Research:
  - Formatting of display elements in the cockpit
  - The impact of advanced weather displays on flight crew workload
  - The impact of advanced weather displays on flight crew situation awareness
  - Alerting algorithms and stimuli within advanced weather displays
  - Collaborative decision making in reaction to weather information

Flightdeck Display Research - Introduction

- Goal of this Research:
  - Investigate teamed decision making to unreliable weather information.
  - Investigate trust that flight crews exhibit toward existing, planned weather displays.
  - Investigate how reactions change when Captain is PF versus when FO is PF.

Flightdeck Display Research - Introduction

- Hypotheses:
  - Decision accuracy would be greatest when onboard and NEXRAD weather sources agreed.
  - Flight crews would show more trust, lower workload and greater situation awareness when displays agreed.
  - Conflict between onboard and NEXRAD displays would trigger a participatory leadership style and greater communication when weather was close.

Flightdeck Display Research - Method

- Design: 4 (weather distance) X 3 (weather display) X 2 (pilot flying)
  - All variables manipulated within groups
  - Dependent Variables: Deviation decision accuracy (evaluated by expert pilots); pilot confidence in deviation decision, perceived situation awareness, perceived workload, and trust in both onboard and NEXRAD weather information.
  - Additional Dichotomous DVs: leadership style (participative or democratic) and communication level (low or high).

Flightdeck Display Research - Method

- Participants - 15 male-only aviator teams (30 individual aviators) from six airlines (mostly United Airlines) – 12 teams analyzed.
  - Captains' age: 46 to 60 years (M = 55.13, SD = 4.21).
  - FO's age: 34 to 56 years (M = 46.33, SD = 5.79).
  - Glass cockpit experience: 1,100 to 12,000 hours.
  - Pilot flight hours: 5,000 to 19,000 hours.
  - 16 reported experience with integrated weather display.
  - Only 4 pilots had flown with their teammate prior to the study.

Flightdeck Display Research - Method

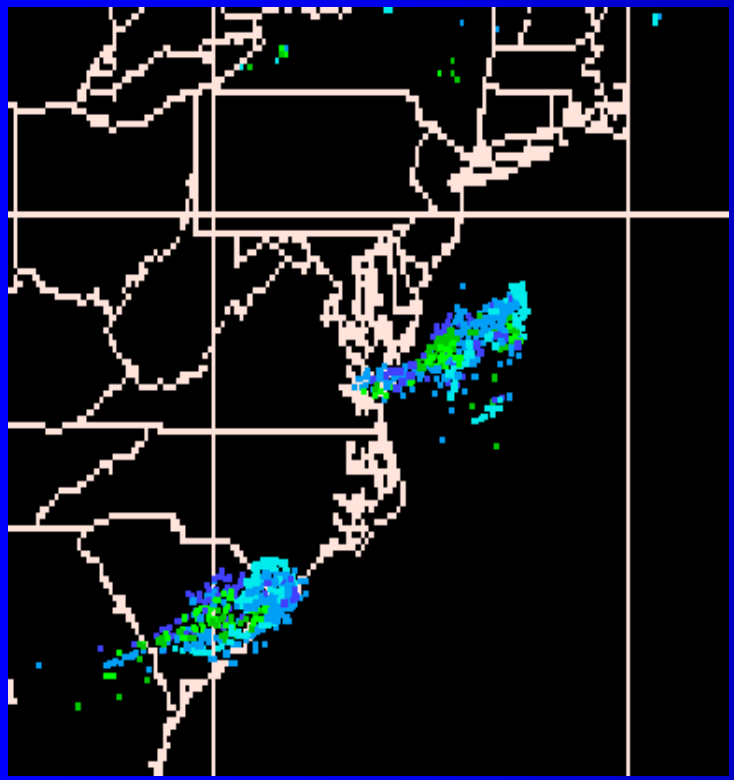
- Materials
  - Computer 1: Microsoft Flight Simulator 2004; connected to the Rudder Control Module, Sub Panel Assembly, external power quadrants and avionics stacks of the EPIC AV-B/IFR General Aviation Flight Console.
  - Computer 2: Hosted Visual Basic 6.0; displayed two sources of weather information to pilot, and several questionnaires (weather deviation, background, SART, TLX, Trust)
  - Computer 3: Same questionnaires as Computer 2 for PF.

Flightdeck Display Research - Method

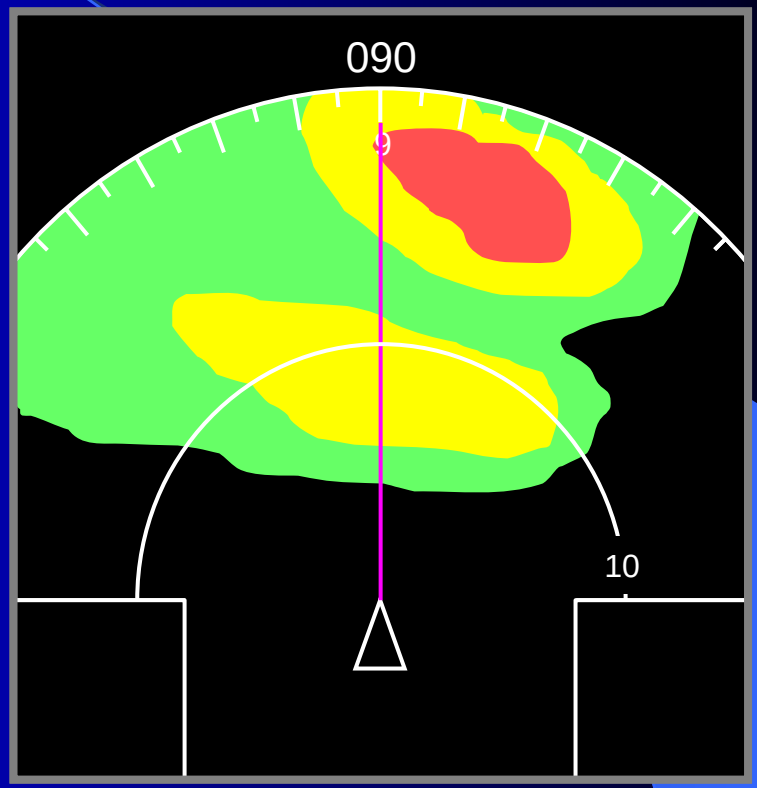
Pilot Flying Display

Pilot Not Flying Display (During Weather Event Presentation)

Flightdeck Display Research - Method



Sample NEXRAD Display



Sample Onboard Display

Flightdeck Display Research - Method

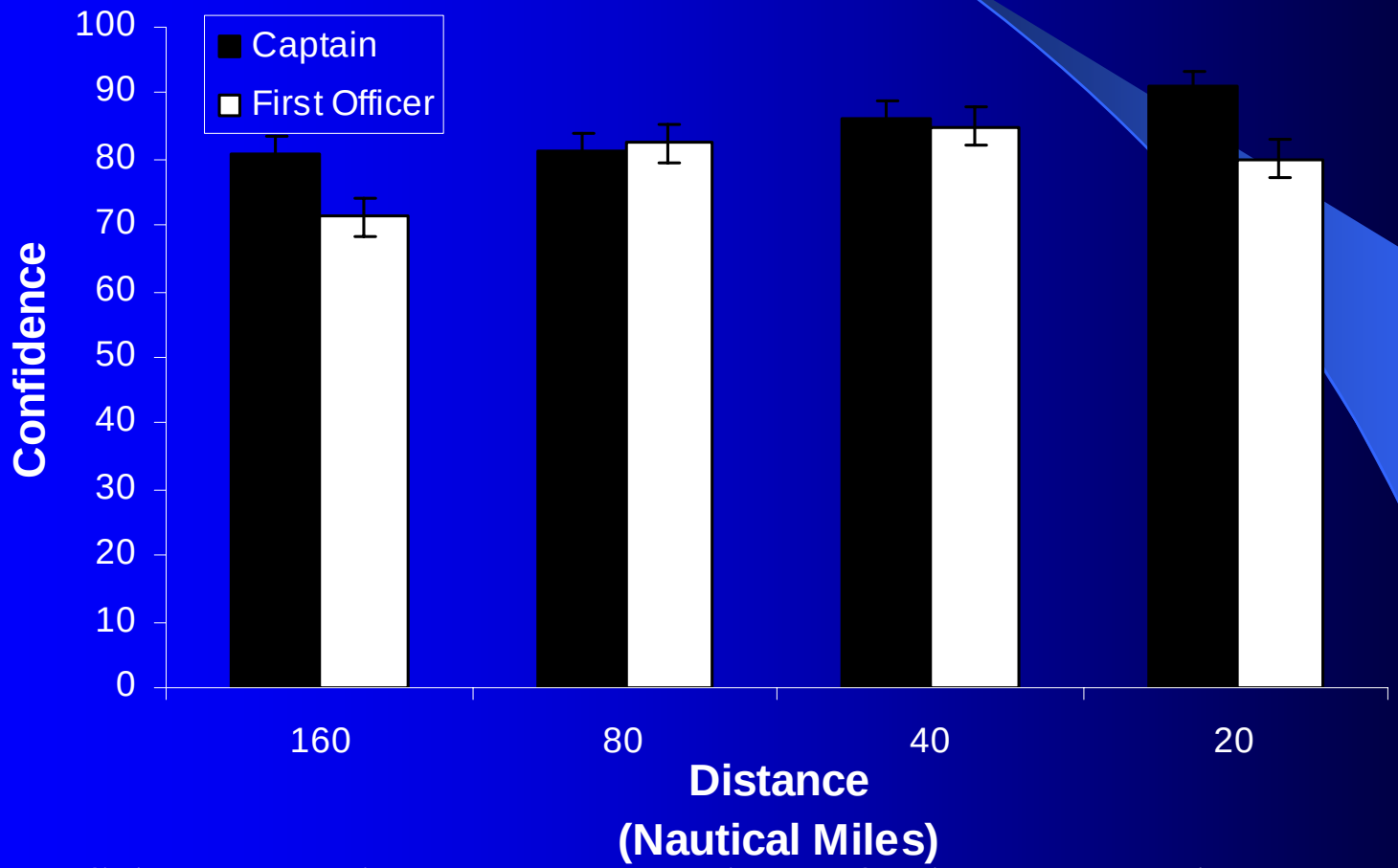
Flightdeck Display Research - Method

- Procedure
  - Recruitment of participants through Lockheed Martin, Swales.
  - Arrival; informed consent
  - Background questionnaires; Pre-briefing
  - Familiarization Flight (SMF-LAX-SMF); two weather events)
  - Experimental Flight (JFK-MIA-JFK); six weather events; flights separated by lunch
  - Opinion Questionnaire
  - Debriefing/Dismissal

Flightdeck Display Research - Results

- Pilot Confidence Ratings (Confidence that Weather Event Actually Existed)
  - Two-way interaction of Pilot Flying and Distance, $F(3, 33) = 3.72$, $p < .05$, partial $\eta^2 = .25$.
  - Main effect of Distance, $F(3, 33) = 3.56$, $p < .05$, partial $\eta^2 = .25$.
    - Greater team confidence when captain flew at 160 nm and 20nm. However, no difference at 80 nm and 40 nm.

Flightdeck Display Research - Results

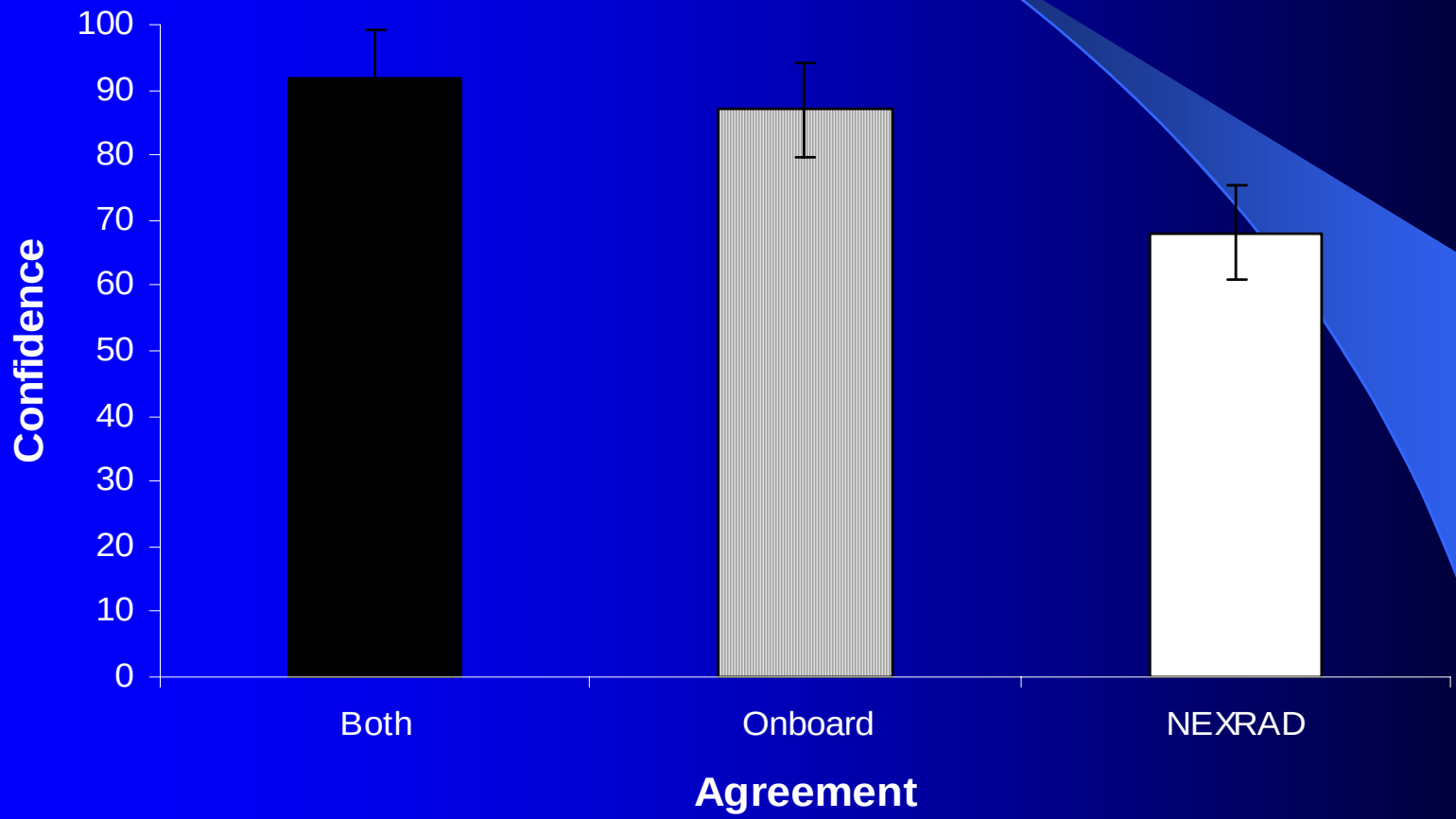


Pilot Confidence Ratings as a Function of Distance to the Weather Event.

Flightdeck Display Research - Results

- Pilot Confidence Ratings (cont.)
  - Main effect of Agreement, $F(1.14, 12.58) = 9.91$, $p < .01$, partial $\eta^2 = .47$.
  - Teams' confidence that weather event actually existed was greater when both systems agreed ($M = 91.83$, $SD = 9.81$) than when only NEXRAD showed the weather event ($M = 68.11$, $SD = 34.04$).

Flightdeck Display Research - Results

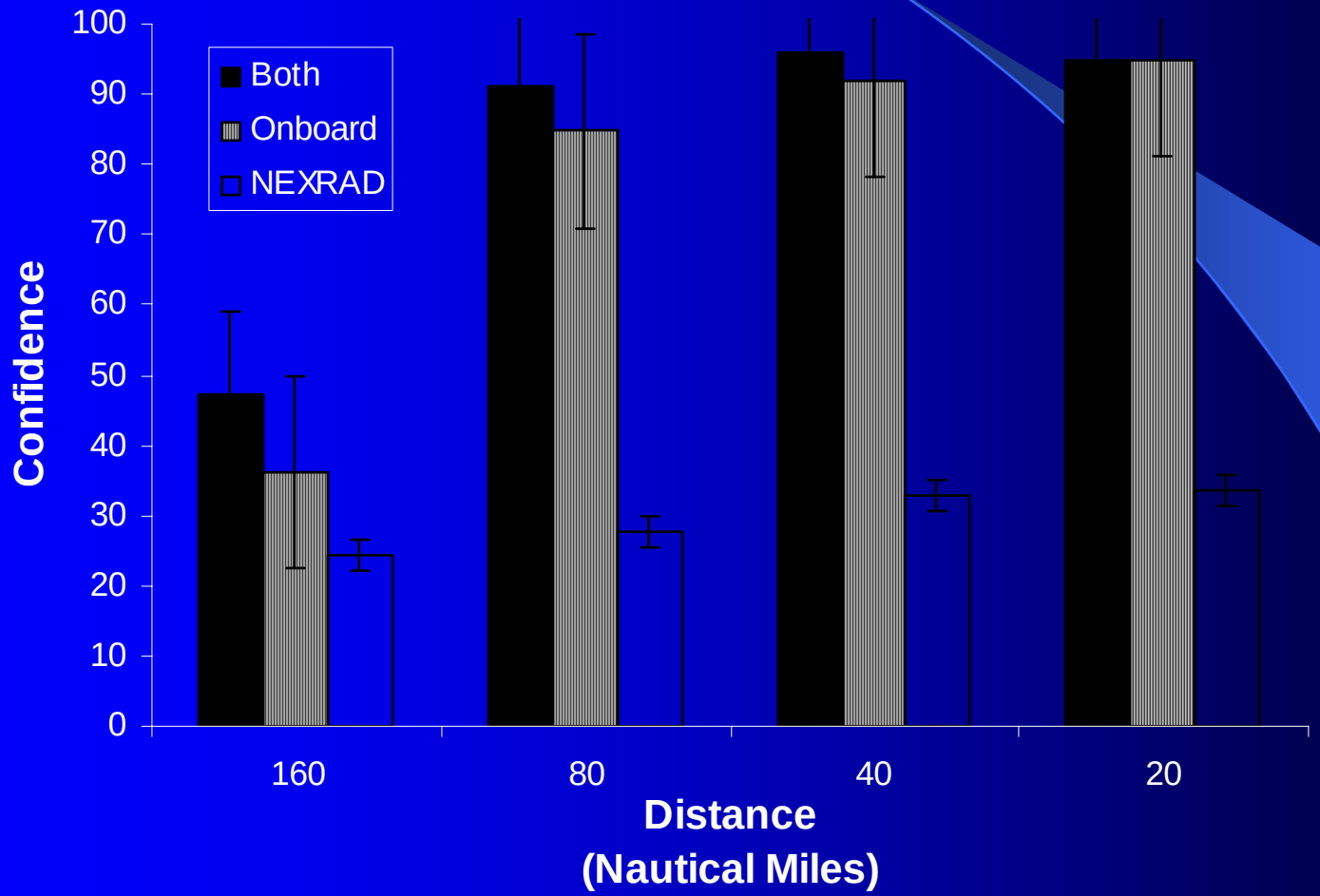


Decision Confidence Level as a Function of Display Agreement.

Flightdeck Display Research - Results

- Confidence that Flight Crew Should Deviate
  - Two-way interaction of Agreement and Distance, $F(2.76, 30.38) = 6.86$, $p < .01$, partial $\eta^2 = .38$.
  - Main effect of Agreement, $F(1.36, 14.96) = 52.13$, $p < .001$, partial $\eta^2 = .83$.
  - Main effect of Distance, $F(1.22, 13.41) = 22.13$, $p < .001$, partial $\eta^2 = .67$.
    - Confidence improved with distance when both systems agreed, $F(1.07, 24.68) = 26.68$, $p < .001$, partial $\eta^2 = .54$.
    - Confidence improved when only the Onboard system indicated the upcoming weather event, $F(1.16, 26.69) = 35.15$, $p < .001$, partial $\eta^2 = .60$.

Flightdeck Display Research - Results



Confidence Levels as a Function of Distance to the Weather Event and Weather Event Display.

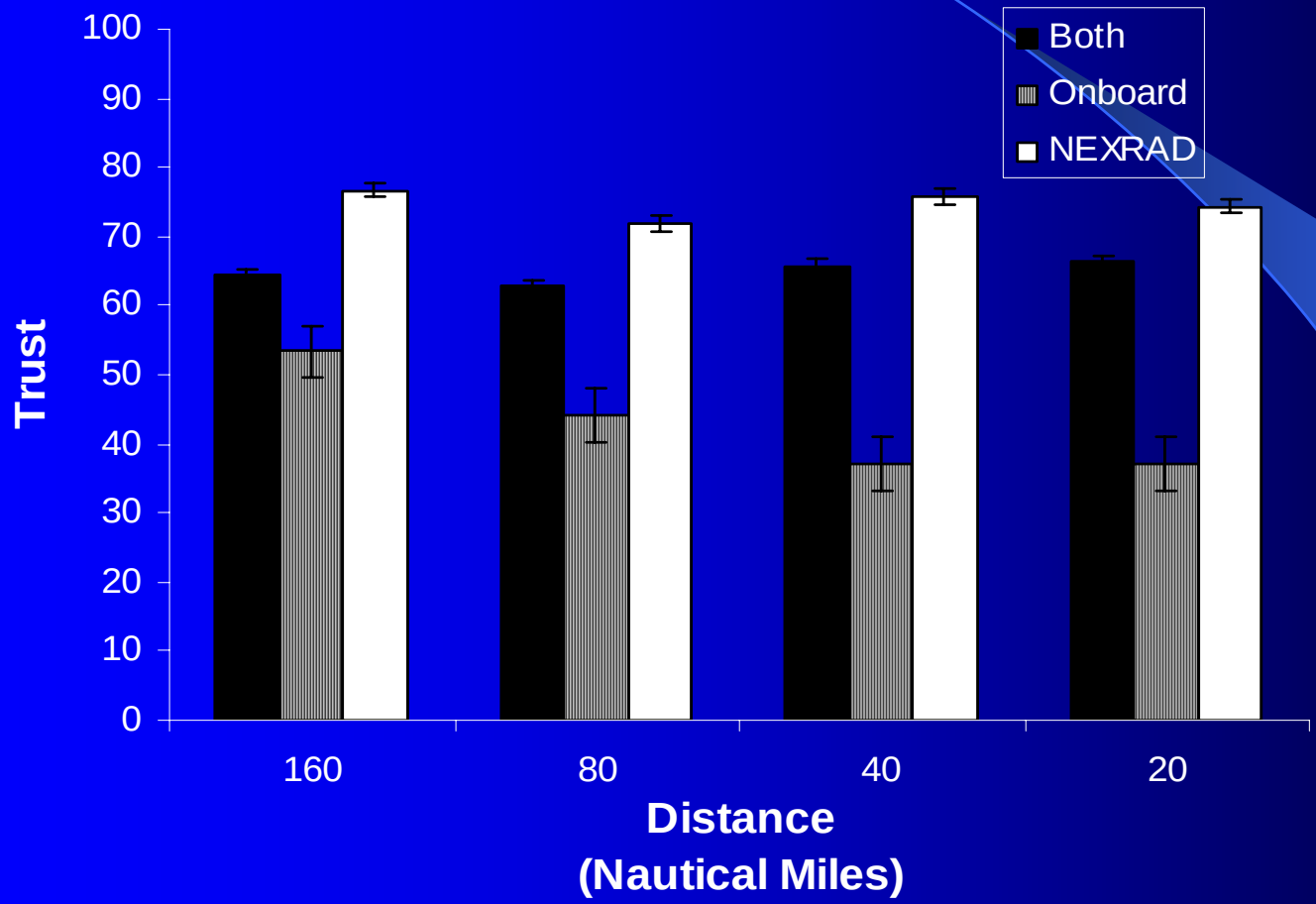
Flightdeck Display Research - Results

- Trust
  - Psychometric evaluation – internal consistency r =.98.
  - Effect of pilot, pilot flying, system, systems' agreement, and distance on pilots' trust through a 2X2X2X3X4 mixed ANOVA.
  - Three-way interaction of System, Agreement, and Distance, $F(3.12, 69.45) = 9.82$, $p < .001$, partial $\eta^2 = .31$.
  - Two-way interaction of System and Agreement, System and Distance, & Agreement and Distance.
  - Main effects of System, $F(1, 22) = 37.31$, $p < .001$, partial $\eta^2 = .63$, Agreement, $F(2, 40.25) = 16.90$, $p < .001$, partial $\eta^2 = .43$, and Distance, $F(3, 66) = 4.88$, $p < .01$, partial $\eta^2 = .18$.

Flightdeck Display Research - Results

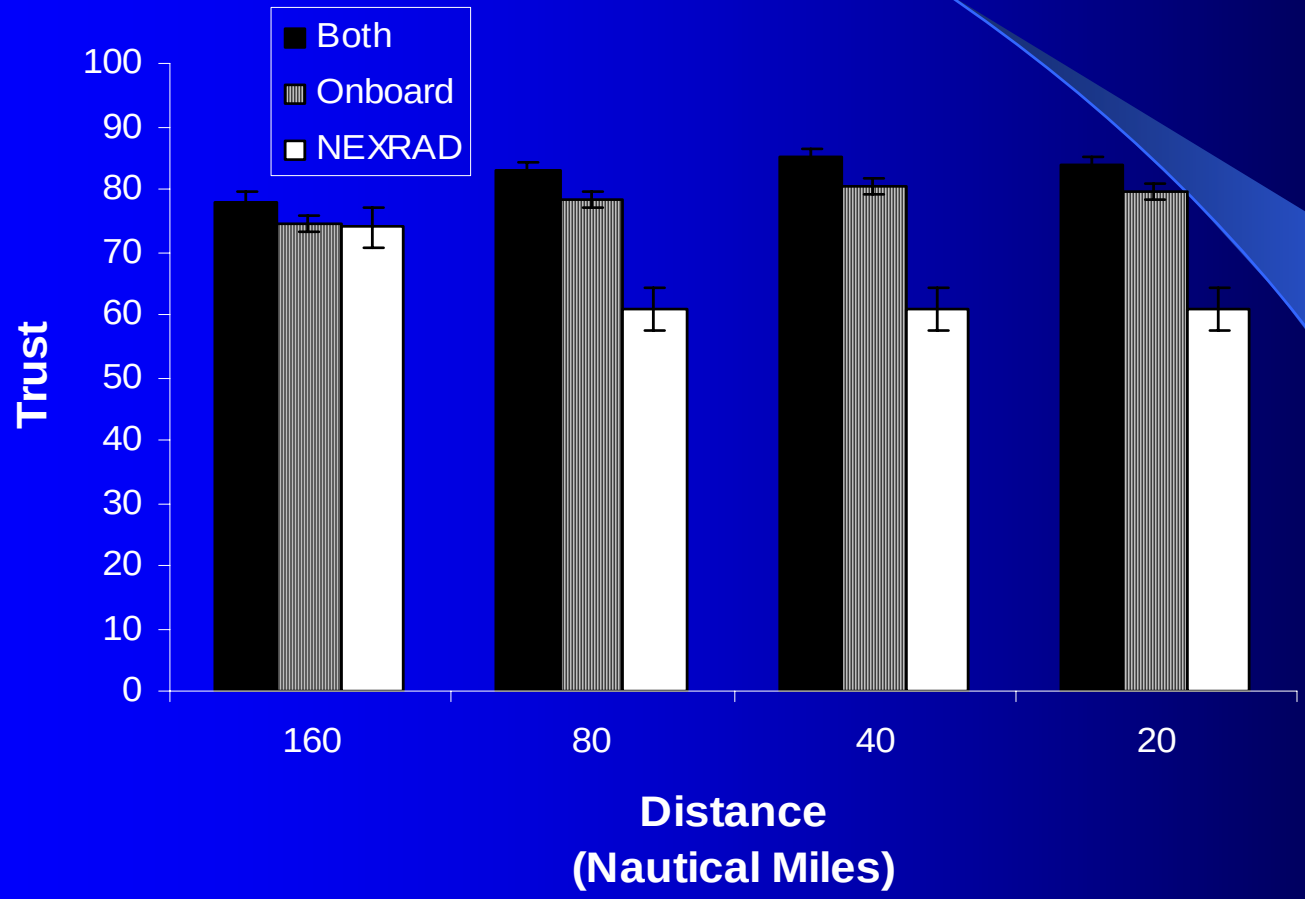
- Trust (cont.)
  - Pilots did not trust NEXRAD when it failed to show close weather events, $F(1.59, 74.66) = 20.49$, $p < .001$, partial $\eta^2 = .30$.
  - Pilots also did not trust the onboard display under the same conditions, $F(2.02, 94.98) = 5.37$, $p < .01$, partial $\eta^2 = .10$.
  - Pilots trusted onboard more to show close weather, $F(1.99, 93.39) = 3.49$, $p < .05$, partial $\eta^2 = .07$; especially when it agreed with NEXRAD, $F(2.16, 101.60) = 6.12$, $p < .01$, partial $\eta^2 = .12$

Flightdeck Display Research - Results



Pilot Flying Trust in the Weather Display as a Function of Distance to the Weather Event and Display Agreement.

Flightdeck Display Research - Results

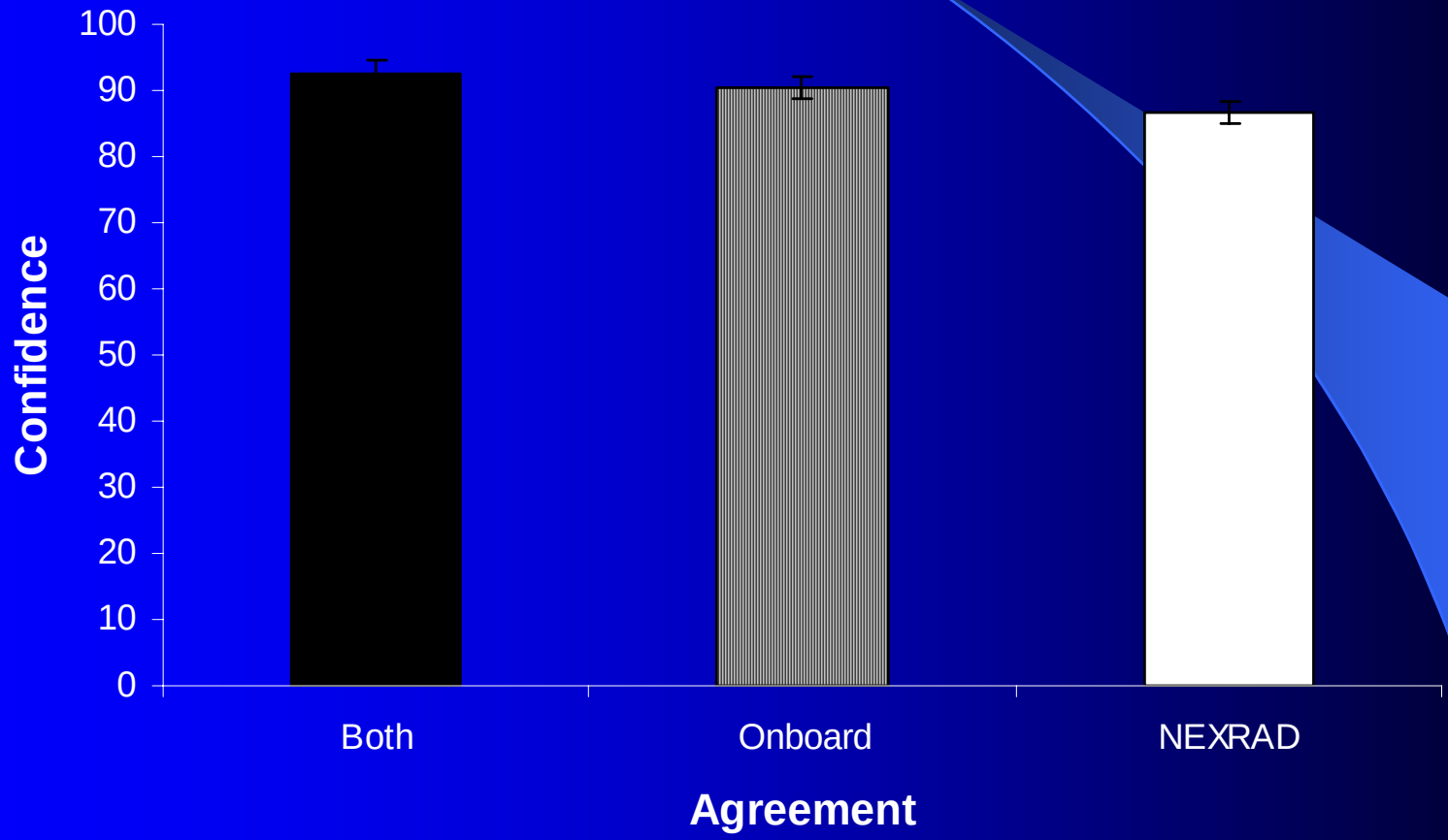


Pilot Not Flying Trust in the Weather Event as a Function of Distance to the Weather Event and Display Agreement.

Flightdeck Display Research - Results

- Deviation Decisions - teams were significantly more likely to want to deviate from the flight path than stay on course, $\chi^2(1) = 28.13$, $p < .001$.
  - Of the 288 deviation decisions made, teams wanted to deviate 189 times.
  - Agreement, distance, and teams' confidence that they should deviate were significant predictors of their deviation decision, $\chi^2(6) = 292.81$, $p < .001$, $R^2 = .64$.
- Decision Confidence – Team confidence was highest when both systems agreed, $F(2, 22) = 3.35$, $p = .05$, partial $\eta^2 = .23$.

Flightdeck Display Research - Results



Confidence in the Deviation Decision as a Function of Weather System Agreement.

Flightdeck Display Research - Results

- Analysis of videotaped recordings
  - Leadership Style
    - Teams were significantly more likely to use a participative leadership style than an autocratic leadership style, $\chi^2(1) = 84.5$, $p < .001$.
    - Only captains' age significantly predicted teams' leadership style, $\chi^2(1) = 60.11$, $p < .001$, $R^2 = .19$.
  - Communication
    - Leadership, captains' age, captains' flight hours, and captains' perceived situation awareness were significant predictors of communication level, $\chi^2(4) = 73.24$, $p < .001$, $R^2 = .23$.

Flightdeck Display Research - Results

- Deviation Decision Accuracy – SMEs specified safety, comfort, and economy as ranked criteria.
  - Teams were more likely to make an accurate than inaccurate deviation decision, $\chi^2(1) = 10.13$, $p < .01$.
  - Agreement, distance, communication, and pilots' trust in the onboard system were significant predictors of teams' deviation decision accuracy, $\chi^2(8) = 61.47$, $p < .001$, $R^2 = .19$.

Flightdeck Display Research - Discussion

- Display agreement predicting deviation accuracy agrees supports importance of redundancy in flight displays (Selcon et al., 1991).
- This also suggests that pilots may integrate weather views from many sources to make deviation decisions (Beringer & Ball, 2004).
- However, marginal predictability reflects the complexity of operational settings; in the real world, ATC, traffic and flight timetables are all present.

Flightdeck Display Research - Discussion

- Relatively low accuracy for deviation decisions – decisions were interdependent, so decisions for distant weather influenced those for closer weather (for better or worse).
- Interesting trends for communication and leadership; however, more detailed analyses need to be done to determine patterns of relationships.

Flightdeck Display Research - Discussion

- Confidence appeared to spike for the onboard and the combination of onboard and NEXRAD systems at the 80 nm range.
- Confidence in the NEXRAD system, however, remained quite low at all weather ranges, reflecting greater crew comfort or familiarity with displays of onboard weather.
- Perhaps one way to integrate these findings is for future weather displays to feature the ability to display raw NEXRAD information in a way that resembles the egocentric viewpoint inherent in the ONBOARD system.

Flightdeck Display Research - Discussion

- Benefits of this Research
  - Actual Pilots, Tested in Teams
  - Actual (Simulated) Flight Task
  - Consideration of Reliability with Other Variables
  - Weather Display Relevance
  - Challenges: Acquiring Equipment, Acquiring Participants, Working with Data

Flightdeck Display Research

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Thank you for your Attention!

Questions?